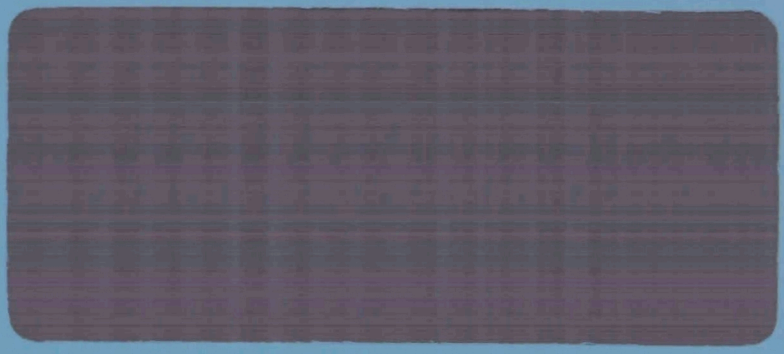

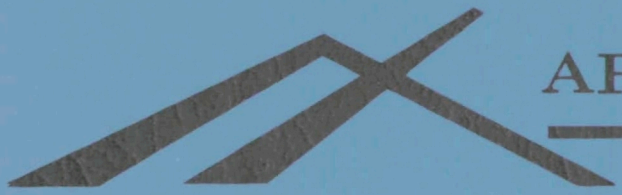

ARDÉ INC

19 INDUSTRIAL AVENUE, MAHWAH, NEW JERSEY 07430

(NASA-CR-120335) VESSEL, PRESSURE GAS STORAGE ARDE P/N D 3870 REVISION A Final Report (Arde, Inc., Mahwah, N.J.) 40 p

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Report No. ARDE FR510561
22 February 1974

FINAL REPORT

OF

VESSEL, PRESSURE GAS STORAGE
ARDE P/N D 3870 REV. A
NASA P/N 20M33152

Prepared For:
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Under:
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ABSTRACT

The fabrication, acceptance testing and qualification testing of hardware which are representative of established fabrication procedures for ARDEFORMed 301 stainless steel tankage is described in this document.

SUMMARY

Five (5) cylindrical pressure vessels intended for high pressure gas storage were fabricated of unaged 301 stainless steel alloy to the configuration as described by drawing D3870 utilizing the ARDEFORM Process.

One (1) of the five (5) units, S/N 31, was hydrostatically burst pressure tested at room temperature to verify the design. The unit burst at 6600 psig which exceeded the design value of 6000 psig.

The units were subjected to the testing as tabulated below and in the sequence indicated with no abnormalities observed.

Examination of Product
Proof Pressure
Volume
Weight
Leakage
Burst Pressure (Qualification Unit Only)

A detailed description of the test procedures can be found in Appendix A.

In addition to the above, four (4) deliverable units were precision cleaned and packaged for oxygen service.

ARDEFORM PROCESS DESCRIPTION

The ARDEFORM Process which makes use of cryogenically stretch formed stainless steel has been developed by ARDE specifically to meet the need for a highly reliable light weight pressure vessel for aerospace applications. Tanks made by the ARDEFORM Process are distinguished by the following characteristics of cryogenically stretch formed stainless steel pressure vessels:

- High Strength to Weight Ratio, $\frac{\sigma}{\rho} \cong 10^6$"
- Excellent Corrosion Resistance
- Excellent Compatibility with a wide range of fluids and propellants
- Exceptional Fracture Toughness at High Yield

  K_c = 200 ksi$\sqrt{\text{in. avg.}}$

  K_{Ic} = 100 ksi$\sqrt{\text{in. avg.}}$

  at 280 ksi Tensile Yield
- Reliable 100% efficient welds
- Simple but closely controlled and reproducible fabrication process

This combination of properties results in a pressure vessel which is almost uniquely qualified to meet a wide range of aerospace propellant and gas storage requirements. The suitability of ARDEFORM for such service has been demonstrated by the many sophisticated projects and aerospace vehicles in which it has been successfully used.

In the ARDEFORM Process, the tank is manufactured by assembling an undersize pressure vessel called a preform which is stretched to final size by pressurizing it with liquid nitrogen while it is immersed in a liquid nitrogen bath. The straining of the 301 alloy at cryogenic temperatures produces a metallurgical transformation of the material with a radical increase in tensile

yield and ultimate strengths. A further increase in strength can be achieved by aging the cryostretched vessel at 800°F for twenty (20) hours. An essential feature of the ARDEFORM Process is the fact that the cryogenic stretching process takes place after all major structural welds have been completed. Each weld in every vessel produced is subjected to a loading which verifies its integrity at a stress well above that which is experienced in conventional proof testing.

In conventional methods of fabricating high strength pressure vessels, hardware is fabricated to a desired size and shape and in some cases, subsequently heat treated to high strength. Final machining completes the process. In contrast, by cryogenic stretch forming, the final size and shapé, as well as strength levels, are achieved simultaneously. The preform must stretch to the final shape. To accomplish this stretching, certain design criteria must be met. For example, in the fabrication of spheres, if one desires to incorporate a boss or a thickened ring, the boss or ring is designed to stretch uniformly with the sphere body.

In order to achieve a reproducible process, ARDE specifies a special chemistry which represents a band within the CRES 301 composition. While this composition is specified with low carbon content, it should be noted that the nature of the ARDEFORM Process is such that a full solution anneal is performed after all welds have been completed. This insures against local alloy depletion which would otherwise occur if carbides formed during welding were allowed to remain in the structure.

TANKAGE DESCRIPTION

The cylindrical tankage as delivered under this program is described by drawing D3870, Figure 1. A photograph of a typical vessel is shown in Figure 2.

The vessel can best be described as being cylindrical in nature with an MS33649-4 port centrally located in one head with a mounting boss in the opposite head which incorporates a blind thread hole for mounting.

The vessel is fabricated utilizing standard roll and weld techniques. Hence, in this process, the cylinder is rolled from flat sheet stock and the heads formed from flat sheet stock also. The bosses are machined from bar stock. The details are then welded together to form a closed pressure vessel which is then cryogenically stretched to final size.

The vessel was designed to contain a minimum volume of seventy (70) cubic inches with a design burst pressure of 6000 psig minimum.

REVISIONS				
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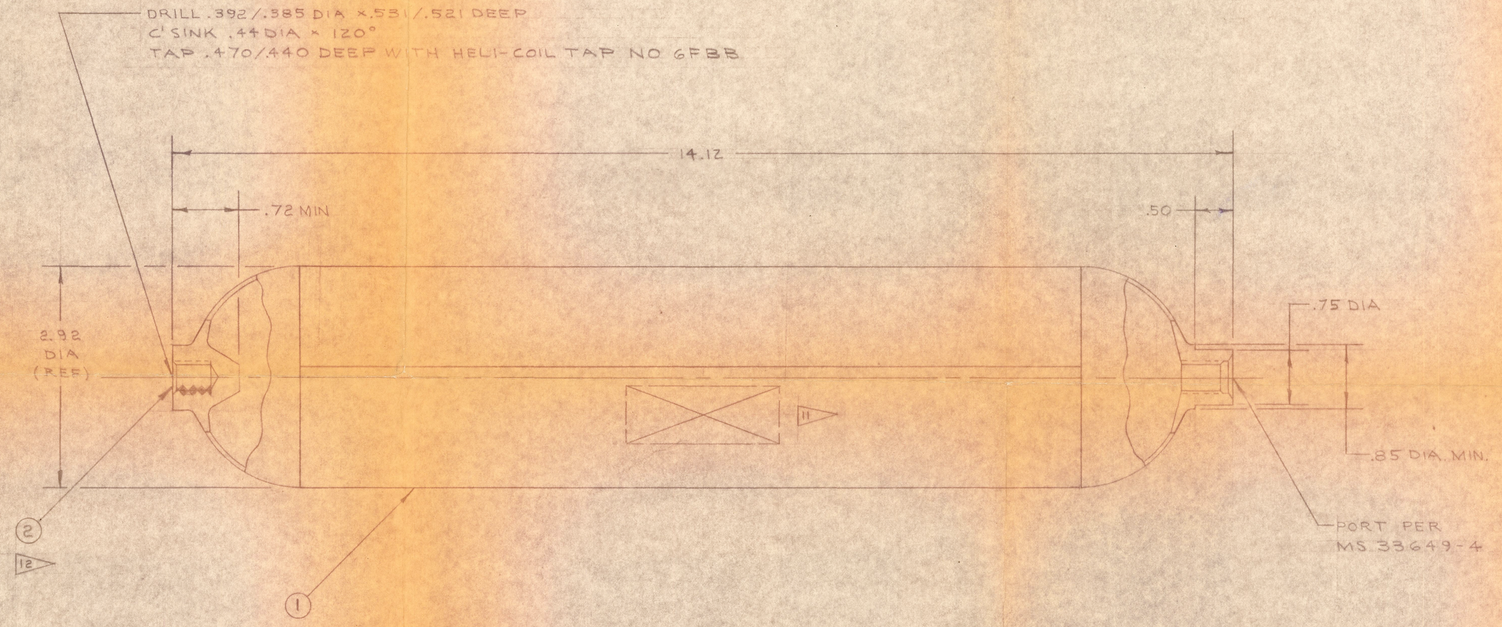
	A	REVISED AND REDRAWN	2-6-73	[illegible]



NOTES:

1. PRESSURE:
   - BURST : 6000 PSIG MINIMUM
   - PROOF : 3000 PSIG
   - OPERATING: 1500 PSIG
   - CYCLE LIFE: 5000 CYCLES MINIMUM FROM 0 PSIG TO 1500 PSIG TO 0 PSIG
2. TEMPERATURE:
   - NON-OPERATING : -40 TO 160°F
   - OPERATING : 59 TO 95°F
3. LEAKAGE: 1×10^{-6} SCC/SEC HELIUM MAXIMUM AT 1500 PSIG
4. WEIGHT: 2.0 LBS MAXIMUM
5. VOLUME: 70 CU. IN. MINIMUM
6. MACHINE PER ARDE SPEC AES 361
7. CLEAN PER ARDE SPEC AES 253
8. VACUBLAST EXTERNAL SURFACES PER ARDE SPEC AES 362
9. PICKLE EXTERNAL SURFACES PER ARDE SPEC AES 251
10. PASSIVATE PER ARDE SPEC AES 254 WITH SOLUTION 'A'
11. SERIALIZE CONSECUTIVELY AND IDENTIFY PER ARDE SPEC AES 601 METHOD 'B' WITH THE FOLLOWING INFORMATION IN THE AREA INDICATED
    - MSFC P/N 20M33152
    - ARDE P/N D3780
    - S/N ___
12. INSTALL ITEM 2 3/4 TO 1-1/2 PITCH BELOW TOP SURFACE AFTER PROCESSING PER NOTE 10
13. PRECISION CLEAN FOR OXYGEN SERVICE PER NASA SPEC MSFC-SPEC-164
14. CRYOFORM PER ARDE SPEC AES 362

QTY REQD PER DASH NO.	ITEM NO.	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
	2		D3870-2	HELI-COIL INSERT	CRES	3591-6GN-0.375
	1		D3870-1	VESSEL		
			D3870	VESSEL ASSEMBLY		

LIST OF MATERIAL OR PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
.X = ± .030, .XX = ± .010,
.XXX = ± .005 ANGULAR ± 30'
BREAK SHARP EDGES .003-.015
ALL SMALL FILLETS .020-.040R
THREADS PER FED. HNDBK H-28 AND SUPPLEMENTS
DIMENSIONING PER MIL-STD-8
WELD SYMBOLS PER JAN-STD-19
SURFACE ROUGHNESS SYMBOLS PER MIL-STD-10
ALL FINISHED SURFACES 125

NEXT ASSEMBLY

DRAWN BY	DM	1-15-73
CHECKER	[illegible]	1-16-73
STRESS ENG'R	[illegible]	1-16-73
METALLURGY	[illegible]	1-16-73
DES. ENG'R	[illegible]	1-16-73
PROJ. ENG'R	[illegible]	1-16-73
MFG	[illegible]	1-16-73
QUAL. CONTROL	[illegible]	1-16-73

ARDE, INC.
PARAMUS, N. J.

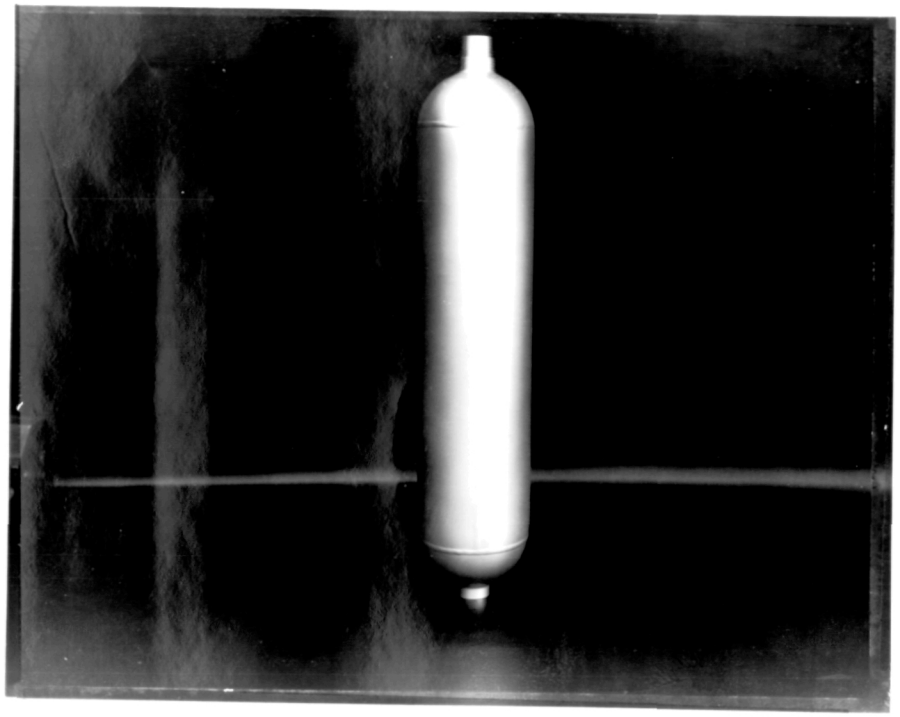
TITLE
VESSEL ASSEMBLY
STORAGE-GAS

SIZE	CODE IDENT NO.	
D	05980	D3870

SCALE 1/1 | WT | SHEET

DAVIS PRESS, INC., BROOKLYN 17, N. Y. REPRODUCIBLE NO. 6400 4788

D3870 M 00



GAS STORAGE PRESSURE VESSEL
P/N D3870
S/N 31

Figure 2

TEST PROCEDURE

The test procedures along with the test specifications and the failure criteria for each of the tests conducted are contained in Appendix A as excerpted from ARDE Specification Number QA510561 entitled, "Acceptance Test Plan and Procedures for Vessel, Pressure - Gas Storage".

The test procedure for the burst test is also included in this section.

TEST RESULTS

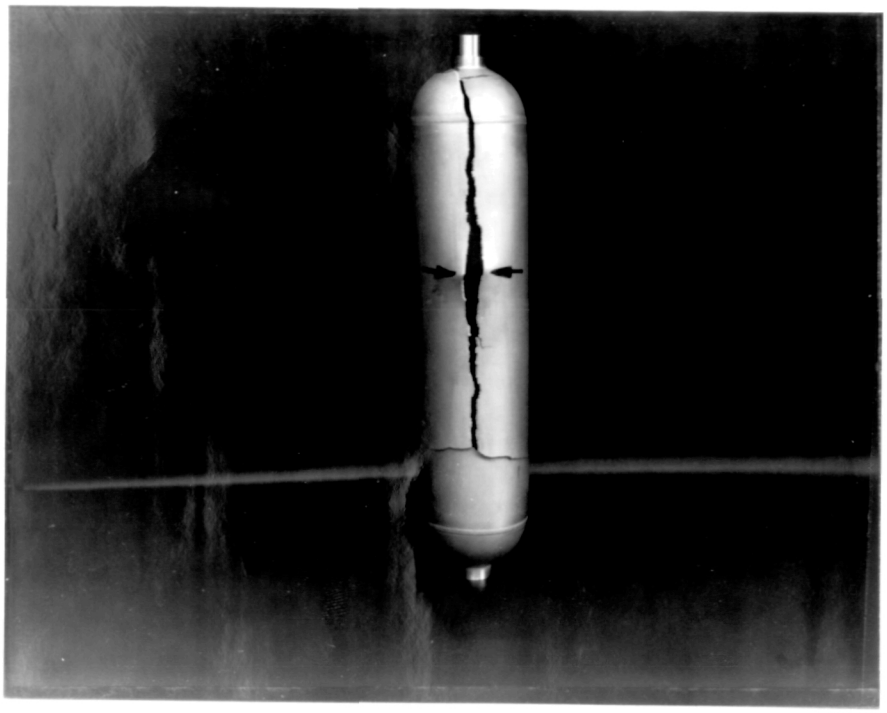
The test results for the vessels fabricated in performance of the program are tabulated in Table I along with the burst test data for the qualification unit.

The test data sheet for the burst test is provided in Appendix B.

A photograph of the S/N 31 unit prior to test is indicated by Figure 2 and a photograph of the unit after burst test is shown in Figure 3 with the origin of failure indicated thereon.

TABLE I
TEST RESULTS

	SPECIFICATION REQUIREMENT	SPECIMEN SERIAL NUMBER 31	32	34	35	37
Weight (LBS)	2.0 Max.	1.54	1.54	1.56	1.54	1.54
Proof Pressure (PSIG)	3000	3000	3000	3000	3000	3000
Volume (Cubic Inches)	70 Min.	73.80	74.03	73.48	73.48	73.76
Leakage (scc/sec Helium at 1500 psig)	1×10^{-6} Max.	6.9×10^{-8}	4.8×10^{-8}	5.94×10^{-8}	8.23×10^{-8}	1.37×10^{-7}
Burst (PSIG)	6000 Min.	6600	----	----	----	----



GAS STORAGE PRESSURE VESSEL
P/N D3870
S/N 31
Post Burst Pressure Test

Figure 3

CONCLUSIONS

Predicated on the test results contained herein, the configuration meets the specification requirements and is acceptable for flight.

DISCUSSION

Review of the acceptance test data indicates no abnormalities with good piece part repeatability.

The unit destructively tested ruptured at a pressure of 6600 psig which is ten (10) percent of the minimum requirement.

The rupture occurred in the parent material approximately 180° from the longitudinal weld. The crack propagated in either direction terminating in the head on the port end with no fragmentation observed.

A photograph of the burst unit is contained in Figure 3.

APPENDIX A

A.1 Proof Pressure Test

A.1.1 Test Specification

To determine if the Pressure Vessel is able to withstand the proof pressurization requirements without deleterious effects. Subsequent testing is required to verify successful compliance.

A.1.2 Test Equipment

a. Heise Gage
Model: N/A
Range: 0-8,000 psi
Calibration Range: Full Scale
Accuracy: ± .125%
Calibration: 90 working days

A.1.3 Test Procedure

a. Position vessel so that one of the port bosses is in an up-right position and fill with demineralized water which meets the requirements of ARDE Specification AES 253.

b. Connect the vessel as shown in proof test set-up. Figure 1.

c. With bleed valve open, start hydro-pump and bleed system. System pressure is not to exceed 10 psig at any time during bleeding operation. During bleeding orient tank approximately per Figure 1 with tube at top center. Fill with water till drainage occurs at tubes and tighten seal caps.

d. Raise system pressure to 100 psig and inspect for leaks if system will not hold pressure.

e. Raise the pressure to 3010 ± 10 psig and hold for 2 minutes minimum.

f. Record pressure and time on data sheet.

g. Depressurize the vessel to ambient pressure.

h. Drain vessel and dry internal surfaces per AES 253.

A.1.4 Failure Criteria

Rupture of the vessel or failure to pass the leakage criteria, Paragraph A.5 shall constitute failure of the proof pressure test. Any indication of defects detectable by visual inspection shall also be cause for rejection.

PROOF TEST SET UP

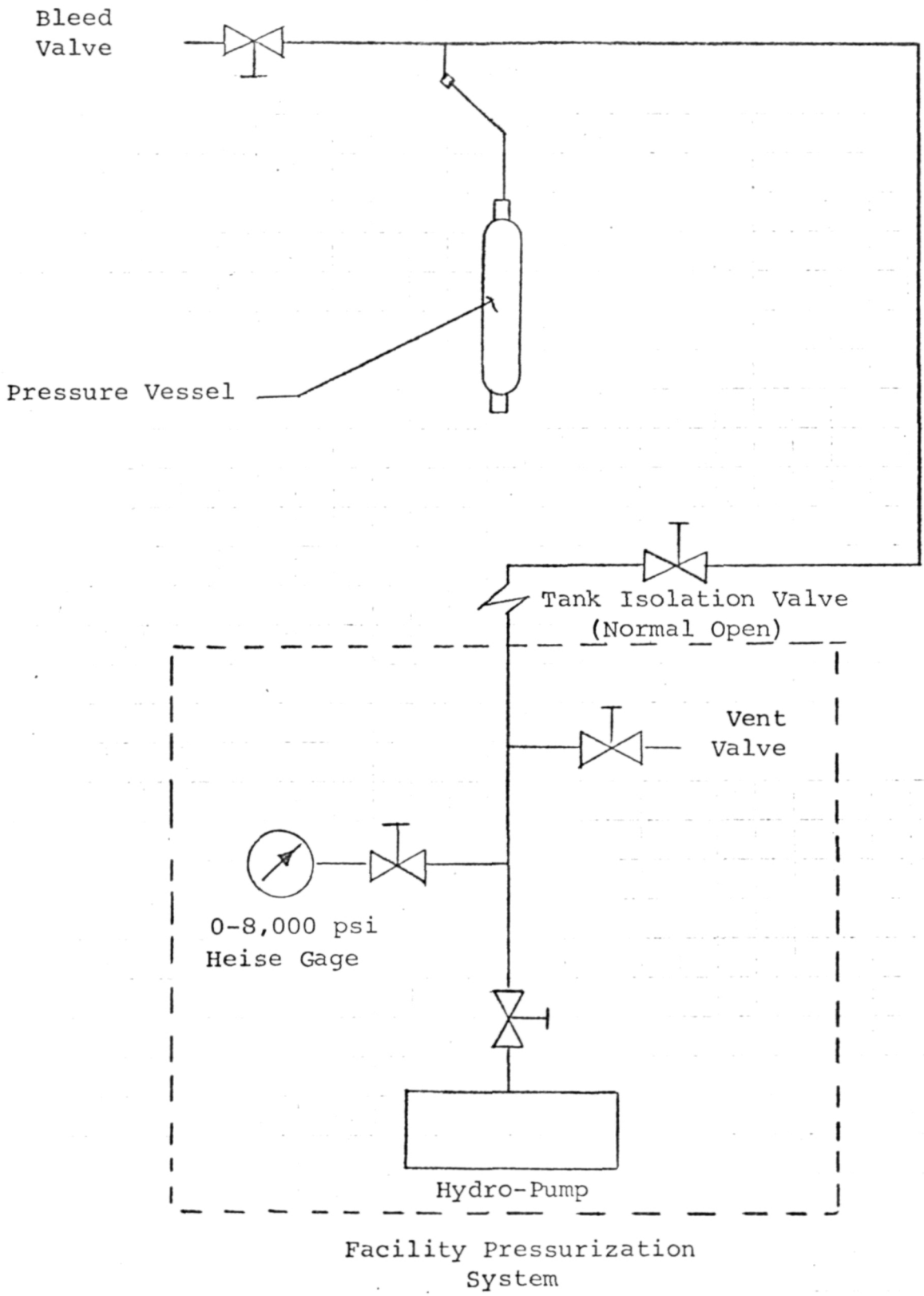


Figure 1

A.2 Examination of Product

A.2.1 Test Specification

To determine if the Pressure Vessel meets dimensional requirements.

The test is also intended to ascertain if the unit has undergone any physical changes after being subjected to a functional or structural test.

A.2.2 Test Equipment

a. Various mechanical measuring devices as set forth on the applicable Inspection Method Sheet.

A.2.3 Test Procedure

a. Compare the unit to Drawing D3870A measuring all required dimensional characteristics and recording all observations.

b. Examine all external and visible internal surfaces as practical for evidence of cracks, corrosion, pitting, deposits, wear or other damage before and after each structural or functional test and record any observations on the Inspection Method Sheet as required.

A.2.4 Failure Criteria

Failure of the unit to comply with the criteria as set forth by Drawing D3870A shall be cause for rejection.

A.3 Weight Determination

A.3.1 Test Specification

To determine if the weight of the Pressure Vessel is below the maximum allowed by specification.

A.3.2 Test Equipment

Howe Scale
Model: 3305
Range: 0-300 lbs.
Calibration Range: Full Scale
Calibration: 2 year intervals
Accuracy: $\pm$ .01 lbs.

A.3.3 Test Procedure

a. Weigh the unit on the Howe Scale.

b. Record the actual weight on the data sheet.

A.3.4 Failure Criteria

A recorded weight in excess of 2.0 pounds shall be cause for rejection.

A.4 Volume Determination

A.4.1 Test Specification

To determine the contained volume of the Pressure Vessel in the unpressurized condition at ambient temperature and pressure.

A.4.2 Test Equipment

a. Howe Scale
Model: 3305
Range: 0-300 lbs.
Calibration Range: Full Scale
Accuracy: ± .01 lbs.
Calibration: 2 year intervals

b. Thermometer
Model: SGA or Equivalent
Range: Record at time of use
Calibration Range: N/A
Accuracy: ± .5°F
Calibration: N/R

A.4.3 Test Procedure

a. Weigh unit dry with port boss plugs. Record on data sheet.

b. Fill unit with demineralized water which meets the requirements of ARDE Specification AES 253. During filling orient tank with tube at top center. Fill with water till drainage occurs.

c. Record water temperature.

d. Weigh filled unit with port boss plugs in place. Record on data sheet.

e. Subtract weight (a) from (d). Record on data sheet.

f. To determine actual volume perform the following calculation:

$$\frac{\text{Weight Recorded (e)} \times 27.69}{\text{Spec. Gravity}} = \text{Cubic Inches}$$

g. Drain vessel and dry internal surfaces per AES 253. Note: This operation can be omitted if the next test is performed immediately thereafter.

A.4.4 Failure Criteria

Failure of the unit to contain a minimum of 70 cubic inches shall constitute non-compliance with the specification requirement.

A.5 Leakage Test - Pressurized

A.5.1 Test Specifications

The purpose of this test is to determine the external leakage rate of the Pressure Vessel when pressurized to operating pressure.

A.5.2 Test Equipment

a. Veeco Leak Detector
Model: 9AS
Range: 2×10^{-10} scc/sec
Accuracy: $\pm$ 2%
Calibration Range: 4.8×10^{-8} scc/sec
Calibration: Prior to use

b. Pressure Gage - Heise
Model: N/A
Range: 0-2000 psi
Accuracy: $\pm$ .125%
Calibration Range: Full Scale
Calibration: 90 working days

c. Bell Jar
Model: N/A
Range: 24" diameter
Accuracy: N/A
Calibration Range: N/A
Calibration: N/R

A.5.3 Test Procedure

a. Determine the sensitivity of the bell jar using a standard of known leakage rate.

b. Place the vessel in the bell jar and connect the vessel and bell jar as shown in the schematic. Figure 2.

c. Pressurize the vessel to 1510 $\pm$ 10 psig with helium gas.

d. Perform the test using a Helium Mass Spectrometer in accordance with ARDE Specification AES 454 Method III with the sensitivity of the instrument such that a helium leakage rate of 1×10^{-6} scc/sec at STP is definitely distinguishable above background.

e. Record results on data sheet.

A.5.4 Failure Criteria

Any helium leakage rate in excess of 1×10^{-6} scc/sec through the vessel walls or welds shall constitute failure of the test.

Leakage Test Setup
Pressurized Test

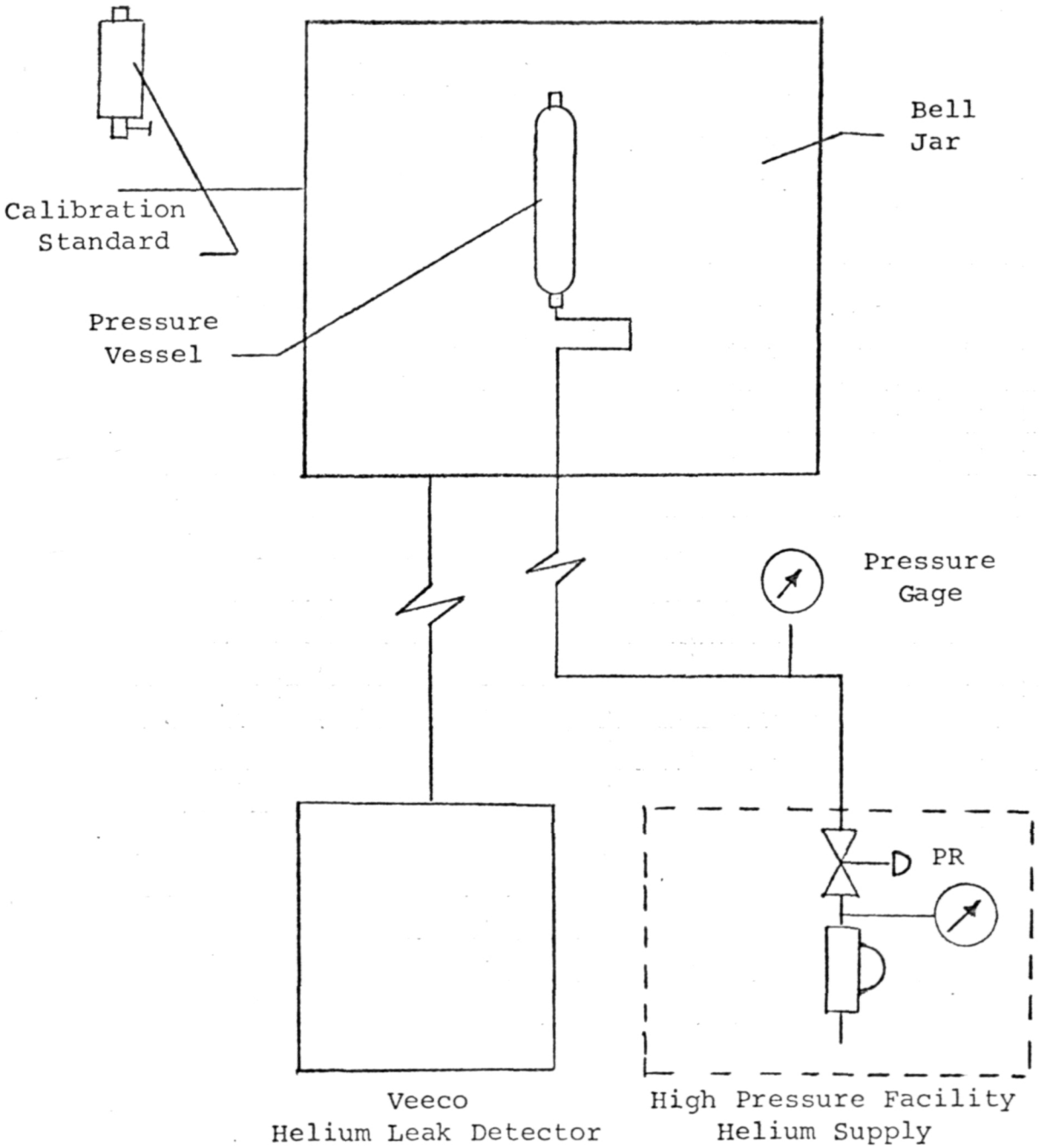


Figure 2

A.6 Burst Pressure Test

A.6.1 Test Specification

To determine if the Pressure Vessel is able to withstand the burst pressurization requirements.

A.6.2 Test Equipment

Heise Gage
Model: N/A
Range: 0-8,000 psi
Calibration Range: Full Scale
Accuracy: ± .125%
Calibration: 90 Working Days

A.6.3 Test Procedure

a. Position vessel so that one of the port bosses is in an up-right position and fill with demineralized water which meets the requirements of ARDE Specification AES 253.

b. Connect the vessel as shown in burst test set-up. Figure 3.

c. With bleed valve open, start hydro-pump and bleed system. System pressure is not to exceed 10 psig at any time during bleeding operation.

d. Raise system pressure to 100 psig and inspect for leaks if system will not hold pressure.

e. Raise the pressure to burst in not less than 15 or more than 300 seconds. Vessel burst shall be greater than 6000 psig.

f. Record pressure and time on data sheet.

A.6.4 Failure Criteria

Rupture of the vessel below 6000 psig shall constitute failure of the burst pressure test.

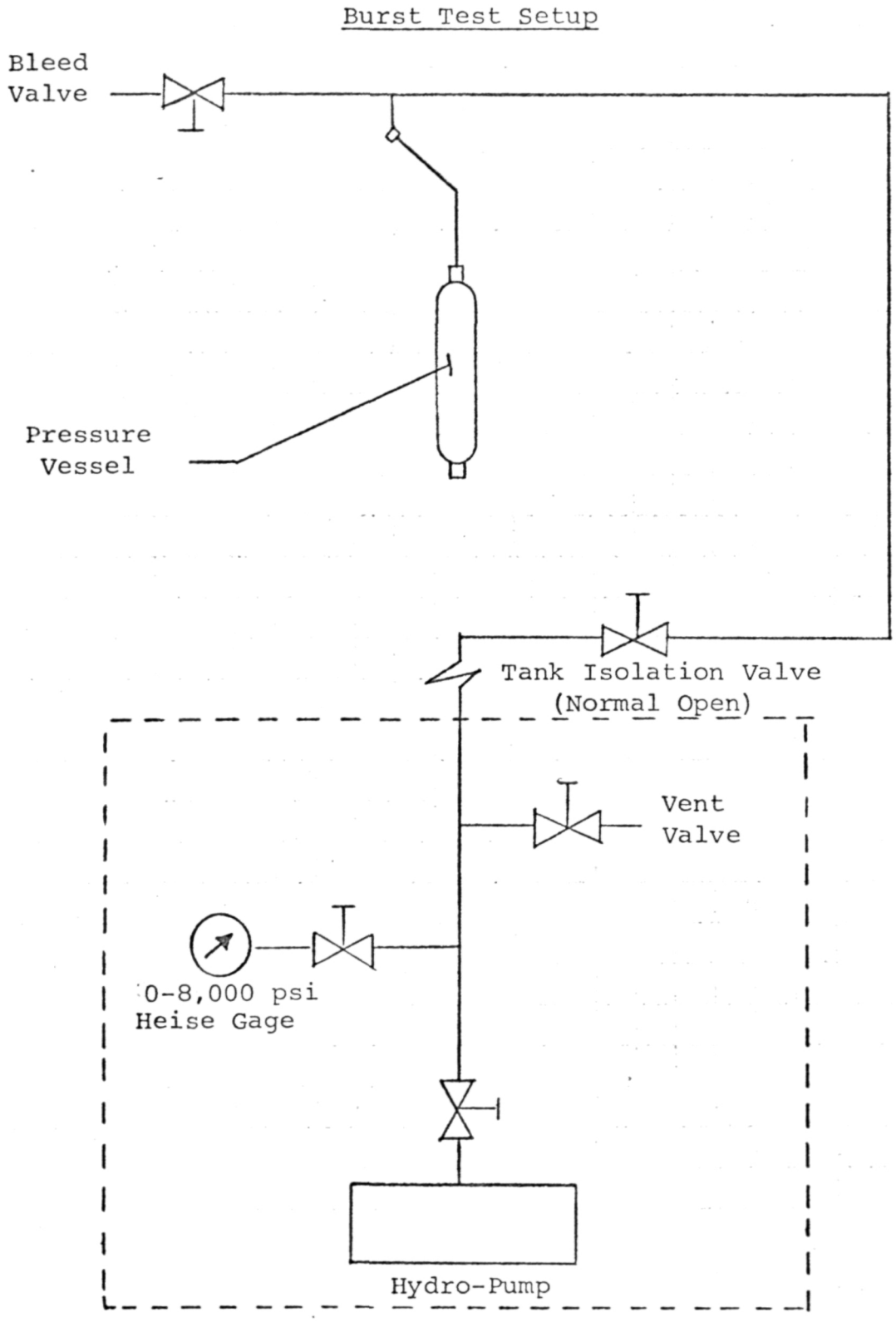

Burst Test Setup
Bleed Valve
Pressure Vessel
Tank Isolation Valve (Normal Open)
Vent Valve
0-8,000 psi Heise Gage
Hydro-Pump
Facility Pressurization System

Figure 3

APPENDIX B

ARDE, INC.

DATA SHEET

BURST PRESSURE TEST

Vessel, Pressure-Gas Storage

ARDE Part Number D3870 Rev. A

NASA Part Number 20M33152 Rev. -

ARDE Serial Number 31

Pressure - Specification: 6000 psig minimum

Pressure at Failure 6600 psig

Remarks: RUPTURE OCCURRED IN PARENT MATERIAL APPROXIMATELY 180° FROM THE LONGITUDINAL WELD. CRACK PROPAGATED IN EITHER DIRECTION ALONG THE CYLINDER AND TERMINATED IN THE HEAD ON THE PORT END

Inspector W Kopec Engineering F. Mello

Test Date 2/19/74 Date 2/19/74